भारतीय मानक
Indian Standard

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(Reaffirmed 2020)

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(दूसरा पुनरीक्षण)

Freeboard Requirement in Dams — Guidelines

(Second Revision)

ICS 93.16

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Dams and Spillways Sectional Committee, WRD 9

FOREWORD

This Indian Standard (Second Revision) was adopted by the Bureau of Indian Standards, after the draft finalized by the Dams and Spillways Sectional Committee had been approved by the Water Resources Division Council.

This standard was first published in 1983. The first revision of this standard was done in 1993 and was applicable only to embankment dams while freeboard for concrete/masonry dams had been covered under IS 6512 : 1984 'Criteria for design of solid gravity dams (*first revision*)'. Since methodology in both cases is based on the method recommended by T. Saville, it has been decided to have a common standard for both types of dams. This revision incorporates the changes on this account.

For the purpose of deciding whether a particular requirement of this standard is complied with, the final value observed or calculated, expressing the result of a test or analysis, shall be rounded off in accordance with IS 2 : 1960 'Rules for rounding off numerical values (*revised*)'. The number of significant places retained in the rounded off value should be the same as that of the specified value in this standard.

Indian Standard

FREEBOARD REQUIREMENT IN DAMS — GUIDELINES

(Second Revision)

1 SCOPE

This standard gives guidelines regarding procedures for working out freeboard for embankment and concrete/masonry dams.

2 REFERENCES

The following standards contain provisions which, through reference in this text constitute provisions of this standard. At the time of publication, the editions indicated were valid. All standards are subject to revision and parties to agreements based on this standard are encouraged to investigate the possibility of applying the most recent editions of the standards indicated below.

IS No.	*Title*
875 (Part 3) : 1987	Code of practice for design loads (other than earthquake) for buildings and structures : Part 3 Wind loads
6512 : 1984	Criteria for design of solid gravity dams (*first revision*)

3 TERMINOLOGY

For the purpose of this standard, the following terms shall apply.

3.1 Design Wave Height — It is that wave height for which the structure is designed to withstand so that it does not undergo more than the accepted probability of damage. It is a suitable multiple of the significant wave height depending on the degree for risk to be accepted.

3.2 Fetch Length — It is the horizontal distance along the wind direction (along central radial of fetch) over open water on which the wind blows.

3.2.1 *Effective Fetch* — It is the weighted average fetch length of water spread, covered by 45^o on either side of trial fetch (assuming the wind to be completely non-effective beyond this area) and measured in a direction parallel to the central radial line of the trial fetch.

3.3 Free Board — It is the vertical distance between the crest of dam (excluding camber) and the normal operating reservoir level.

3.3.1 *Normal Free Board* — It is the freeboard above the full reservoir level (FRL).

3.3.2 *Minimum Freeboard* — It is the freeboard above the maximum water level (MWL) worked out for designed inflow flood (DIF).

3.4 Maximum Wave Height — It is the average wave height of the highest one percent of waves in a representative spectrum.

3.5 Significant Wave Height — It is the average wave height of the highest one-third of the waves present in each sampling interval

3.6 Wave Length — It is the length in between successive crests or troughs for significant wave.

3.7 Wave Period — It is the average interval in seconds between successive crests or troughs of significant waves.

3.8 Wave Run-up — It is the difference (vertical height) between maximum elevation attained by wave run-up on the upstream slope and the still water elevation on this slope excluding wave action.

3.9 Wind Set-up — When wind blows over a water surface it exerts a horizontal force on the water surface driving it in the direction of the wind. This effect results in piling up of the water on leeward side of the lake or reservoir. The magnitude of rise above the still reservoir water surface is called 'wind set-up' or 'wind-tide'.

3.10 Top of Dam — It is the level of dam top ignoring road camber.

4 FACTORS CONSIDERED FOR FREEBOARD ESTIMATE

4.1 The following factors are considered for the estimation of freeboard:

a) Wave characteristics, particularly wave height and wave length;
b) Height of wind set-up above the still water level adopted as freeboard reference elevation; and
c) Upstream slope of the dam and type of dam surface.

4.2 Freeboard requirement does not account for effects of earthquake, settlement of embankment dam and dam foundation, and earthquake seiches.

5 NOTATIONS

For the purpose of this standard the following notations shall apply:

- D = reasonable approximate average depth of water along the fetch length, in m
- F = fetch length, in km
- F_e = effective fetch, in km
- f_e = effective fetch, in m
- g = acceleration due to gravity in m/sec ^{2}
- H = height of any specified wave measured from trough to crest, in m
- H_{Max} = maximum wave height, in m
- H_s = significant wave height, in m
- L_s = wave length of significant wave, in m
- Q = coefficient described as the ratio of wind velocity over the water surface V to the wind velocity on land U
- R = wave run-up, in m
- R_a = designed wave run up corresponding to type of upstream surface
- S = wind set-up, in m
- T_s = wave period of significant wave, in s
- U = maximum wind velocity in measured over land surface during the minimum period of time required for generation of waves, in km/h
- V = wind velocity over water surface, in km/h
- v = wind velocity over water surface, in m/s
- H_o = design/specific wave height, in m

6 METHOD FOR FREEBOARD COMPUTATION

6.1 Out of the available methods for freeboard computations, assistance has been derived from T. Saville's method, which is widely used for freeboard computations of dams. The details of the procedure to be followed for computation of freeboard are given in Annex A and typical computations for freeboard are given in Annex B.

6.2 The freeboard should be calculated for following conditions:

a) Normal freeboard, that is at FRL; and
b) Minimum freeboard, that is at MWL.

The freeboard which gives the highest level for top of dam should finally be adopted.

6.3 Normal Freeboard

While calculating normal freeboard at FRL, full wind velocity should be adopted. The design wave height (H_o) be taken as 1.67 times the significant wave height (H_s). Normal freeboard should not be less than 2.0 m in case of embankment dam.

6.4 Minimum Freeboard

While calculating minimum freeboard at MWL, two-third wind velocity should be adopted. The design wave height (H_o) be taken as 1.27 times the significant wave height (H_s). The freeboard should be subject to a minimum of 1.5 m in case of embankment dam and 1.0 m for concrete/masonry dam.

7 OTHER RELATED FEATURES

7.1 PMF Considerations

If the design flood is different from probable maximum flood (PMF), top of dam should not be lower than MWL corresponding to PMF.

7.2 Parapet Wall

7.2.1 1.0 m high solid parapet wall may be provided in all dams on the upstream side, but the same is not to be considered as a part of freeboard.

7.2.2 The reservoir side of parapet wall may be curved to act as deflector in case of embankment dam.

7.2.3 In the circumstances where RCC deflector wall is provided in the earth dam, its height may be restricted to 1.5 m. The height of deflector wall in excess of 1.0 m may be considered as part of the freeboard.

ANNEX A

(*Clause* 6.1)

PROCEDURE FOR COMPUTATION OF FREEBOARD FOR DAMS

A-0 Step by step procedure for computation of freeboard for dams is explained below. The procedure is illustrated through an example given in Annex B.

A-1 NORMAL FREEBOARD

A-1.1 Select a line *AB*, with '*A*' on dam axis and '*B*' on FRL contour as shown in Fig. 1 so as to cover the maximum reservoir water spread area within 45° on either side of line *AB* (fetch length). Draw 7 radials at 6° a interval on each side of line *AB* and compute effective fetch (F_e) as shown in Fig. 1 for FRL by the following formula:

$$F_e = \frac{\sum X_1 \cos\alpha \cdot \cos\alpha}{\sum \cos\alpha}$$

where X_1 denotes the length of any radial which is at an angle from the central radial.

If felt necessary more trials may be done so that maximum effective fetch may be computed. Enter effective fetch (F_e) as step (1) of Annex B.

A-1.2 From Fig. 1 of IS 875 (Part 3) read basic wind speed on land for 50 years return period (*U*) for region in which proposed dam falls. Enter wind velocity on land (*U*) as step (2).

A-1.3 Compute wind velocity on water surface (*V*), by multiplying coefficient *Q* from Table 1 corresponding to effective fetch to the wind velocity on land (*U*). Enter *Q* and wind velocity on water surface as steps (3) and (4) respectively.

A-1.4 Using relationship given below or graphical diagram shown in Fig. 2 and Fig. 5, compute significant wave height (H_s)

$$g.H_s/v^2 = 0.002\,6\,(g.f_e/v^2)^{0.47} \qquad \ldots(1)$$

Enter significant wave height (H_s) as step (5).

A-1.5 Using relationship given below or graphical diagram shown in Fig. 3, compute wave period (T_s)

$$g.T_s/v = 0.46\,(g\,f_e/v^2)^{0.28} \qquad \ldots(2)$$

Enter T_s as step (6).

A-1.6 Compute wave length (L_s) with the following relationship:

$$L_s = 1.56\,T_s^2 \qquad \ldots(3)$$

Enter L_s as step (7).

A-1.7 Compute design wave height H_o with the relationship given in **6.3** and **6.4**.

$H_o = 1.67\,H_s$ (For Normal free board)

$H_o = 1.27\,H_s$ (For Minimum free board)

Enter H_o as step (8)

A-1.7.1 Using the table below, select design wave height (H_o) as that specific height which is exceeded by only 4 percent waves.

Percentage of waves exceeding specific wave height (H_o)	0.4	2	4	8	13
$Ratio = \dfrac{\textit{Specific wave height } (H_o)}{\textit{Significant wave height } (H_s)}$	1.67	1.4	1.27	1.12	1.0

Higher percentage of wave exceeding H_o may be considered for small dams as they are not likely to cause damage to life and property in case of breach. Lower percentage may be considered in case of large dams.

NOTE — **A-1.7** is for embankment dams and **A-1.7.1** is for concrete and masonry dams.

A-1.8 Work out steepness ratio H_o/L_s. With the help of curves given in graph in Fig. 4, between different values of steepness ratio and the dam slopes read R/H_o ratio. and compute wave run up on smooth surface (*R*). The wave run up on rough surface (R_a) may be computed by multiplying surface roughness coefficient, given in Table 2, to the wave run up on smooth surface (*R*).

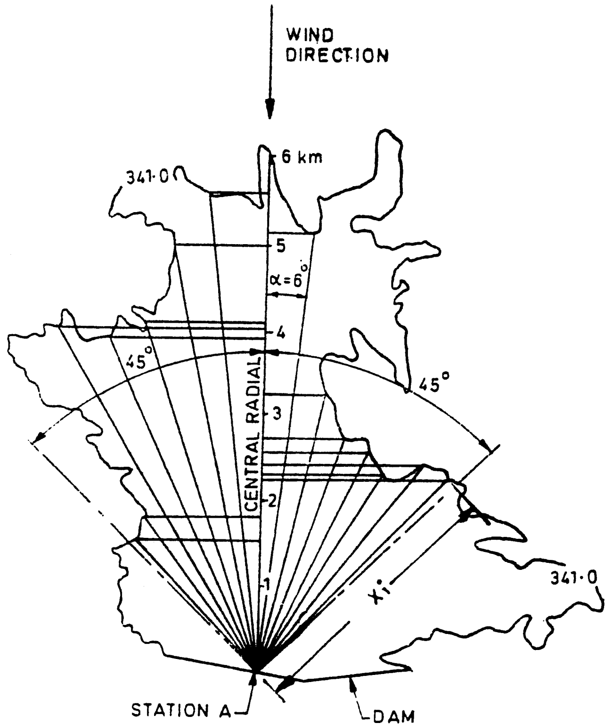
Enter H_o/L_s, R/H_o, *R* and designed R_s corresponding to upstream dam surface as step (9), (10), (11) and (12) respectively.

NOTE — If the wave run-up on rough surface (R_a) calculated above is less than the designed wave height (H_o) as obtained as step 7, keep $R_a = H_o$.

Table 1 Wind Velocity Relationship from Land to Water

(*Clause* A-1.3)

Effective Fetch, in km (F_e)	1	2	4	6	8	10 and above
Coefficient *Q*(*V/W*)	1.1	1.16	1.24	1.27	1.30	1.31



α	cos α	X_i	X_i cos α	X_i cos α. cos α
42°	·743	2·08	1·55	1·151
36°	·809	2·29	1·85	1·499
30°	·866	4·73	4·10	3·550
24°	·914	4·32	3·95	3·610
18°	·951	4·26	4·05	3·851
12°	·978	5·11	5·00	4·890
6°	·995	5·68	5·65	5·621
0°	1·000	6·00	6·00	6·000
6°	·995	5·18	5·15	5·124
12°	·978	3·37	3·30	3·227
18°	·951	2·95	2·80	2·662
24°	·914	2·90	2·65	2·422
30°	·866	2·77	2 40	2·078
36°	·809	3·09	2·50	2·023
42°	0·743	3·16	2·35	1·746
	Σ = 13·512			Σ = 49·454

$$F_e = \frac{\Sigma X_i \cos\alpha . \cos\alpha}{\Sigma \cos\alpha} = \frac{49{\cdot}454}{13{\cdot}512} = 3{\cdot}66 \text{ km}$$

FIG. 1 COMPUTATION OF EFFECTIVE FETCH

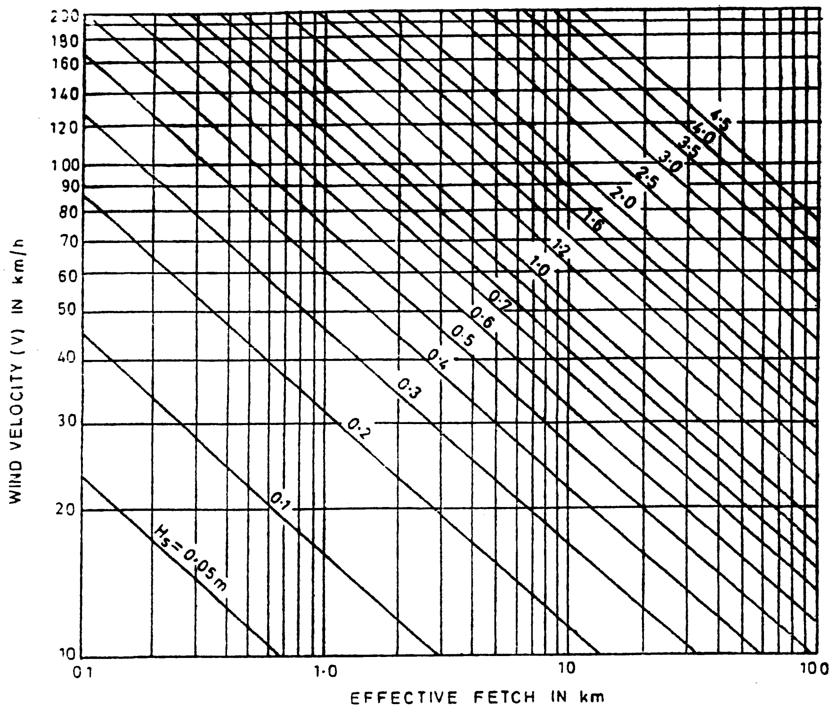


FIG. 2 CORRELATIONS OF SIGNIFICANT WAVE HEIGHTS (H_s) WITH RELATED FACTORS FOR EMBANKMENT DAMS

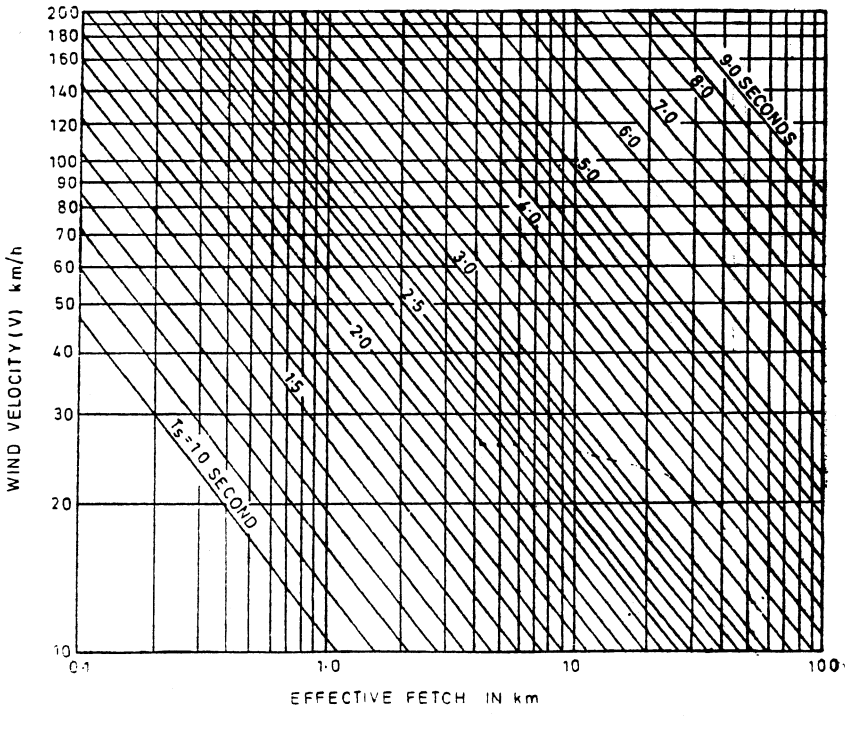


FIG. 3 RELATION BETWEEN WAVE PERIODS (T_s) AND RELATED FACTORS

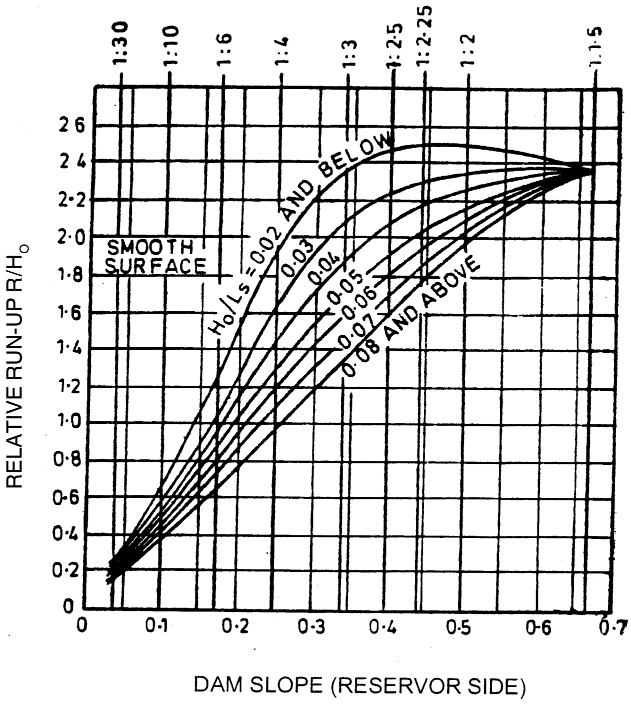


FIG. 4 WAVE RUN-UP RATIOS *VERSUS* WAVE — STEEPNESS AND UPSTREAM SLOPE

A-1.9 Calculate average water depth (*D*) along fetch length (*F*). Enter average reservoir depth (*D*) as step (13).

A-1.10 Compute wind set-up (*S*) from the formula :

$$S = (V^2 . F) / (62\ 000\ D) \qquad .....(4)$$

If wind set-up as calculated above is higher than the average depth of water, the value of wind set-up should be limited to average depth of water. Enter wind set-up as step (14).

A-1.11 Compute freeboard as step (12) + step (14). Enter as step (15).

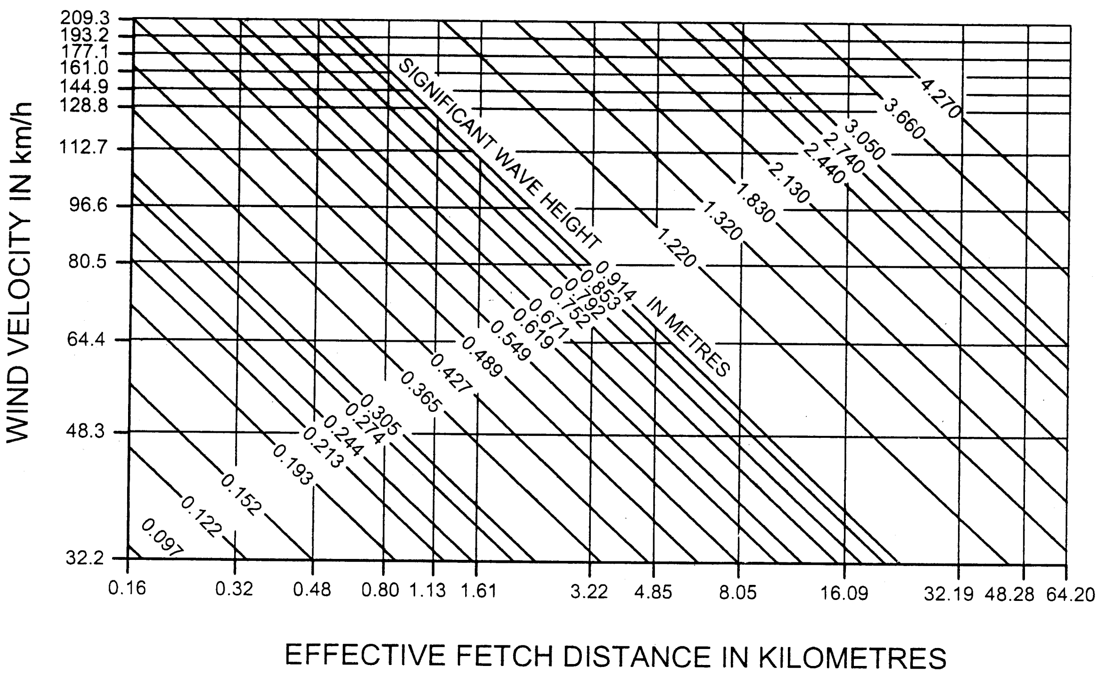


FIG. 5 CORRELATION OF SIGNIFICANT WAVE HEIGHTS (H_s) WITH RELATED FACTORS FOR CONCRETE/MASONARY DAMS

Table 2 Surface Roughness Coefficient
(*Clause* A-1.8)

Sl No.	Type of Dam Surface	Recommended Coefficient
(1)	(2)	(3)
i)	Cement concrete surface	1.0
ii)	Flexible brick pitching	0.8
iii)	Hand placed rip rap:	
	a) Laid flat	0.75
	b) Laid with projection	0.60
iv)	Dumped rip rap	0.50

A-1.11.1 Workout computed free board as sum of $1\frac{1}{3}$ times the value in step 8 and value in step (14) and enter in step (15).

NOTE — **A-1.11** is for embankment dams and **A-1.11.1** is for concrete and masonry dams.

A-1.12 Check, if freeboard calculated in step (15) fulfil the norms given in **6.3.** Enter required freeboard as step (16).

A-2 MINIMUM FREEBOARD AT MWL

For obtaining minimum freeboard at MWL repeat above procedure by calculating fetch length (F) and effective fetch (F_e) at MWL. The freeboard so calculated should be modified, if required as per norms given under **6.4**.

A-3 FIXING TOP OF DAM

Calculate the top of dam required for the following conditions and enter as step (17).

a) FRL + Normal freeboard (as per **6.3**); and
b) MWL + Minimum freeboard (as per **6.4**).

Adopt the highest of the above two values as top of dam.

ANNEX B

(*Clauses* 6.1, A-0 *and* A-1.1)

TYPICAL COMPUTATIONS FOR FREEBOARD

B-1 BASIC DATA

Full reservoir level	—	341.0 m
Max. water Level	—	343.2 m
Fetch length	—	6 km (*see* Fig. 1).
U/S slope of dam	—	1 Vertical: 2.5 Horizontal (Embankment dam)
	—	0.25 Vertical: 1 Horizontal (Concrete/Masonry Dam)

Step No.	*Computed Item*	*Embankment Dam*			*Concrete/Masonry Dam*		
		Normal Freeboard	Minimum Freeboard	Remarks	Normal Freeboard	Minimum Freeboard	Remarks
(1)	(2)	(3)	(4)	(5)	(6)	(7)	(8)
1	Effective fetch (Fe), in km	3.66	4		3.66	4	
2	Wind velocity over land (U), in km/h	150	100	As per **A-1.2** and **6.4**	150	100	As per **A-1.2** and **6.4**
3	Wind coefficient (Q)	1.23	1.24	Table 1 (by interpolation)	1.23	1.24	Table 1 (by interpolation)
4	Wind velocity over water surface (V), in km/h	184.5	124	($Q \times$ Step No. 2)	184.5	124	$Q \times$ Step No.2
5	Significant wave height (H_s), in m	2.38	1.63	Fig. 2 or Eq.1	2.29	1.52	Fig. 5
6	Wave period (T_s), in Seconds	5.0	4.3	Fig. 3 or Eq. 2	—	—	
7	Wave length (L_s), in m	39	28.84	Eq.3	—	—	
8	Design Wave height (H_o), in m	3.97 (1.67 × 2.38)	2.07 (1.27 × 1.63)	As per **A-1.7**	2.91 (1.27 × 2.29)	1.93 (1.27 × 1.52)	As per **A-1.7.1**
9	Wave Steepness H_o/L_s	0.1018	0.072		—	—	
10	Relative Run-up R/H_o	1.6	1.72	Corresponding to u/s slope and Fig. 4	—	—	
11	Run-up (R), in m	6.35	3.56		—	—	
12	Designed 'R_a' considering type of surface	4.76	2.67	Table 2 Take hand placed flat laid rip rap type dam surface	—	—	
13	Average depth of reservoir (D), in m	29.0	31.2		29.0	31.2	
14	Wind set-up, in m	0.11	0.048	Equation 4	0.114	0.05	Equation 4
15	Free board required	4.87	2.72	As per **A-1.11**	4.0	2.62	As per **A-1.11.1**
16	Permissible freeboard	4.87	2.72	As per **A-1.12/ A-2**	4.0	2.62	
17	Top of dam (as calculated)	341+4.87 = 345.87	343.2+2.72 = 345.92	As per **A-3**	341+4.0 = 345.00	343.2+2.62 = 345.82	
18	Top of dam to be provided	345.92 m, say 346.0 m			345.82 m Say 345.90 m		

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Amendments Issued Since Publication

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